STATUS REPORT: STRUCTURAL PERFORMANCE

Project 2695-21 -- Evaluation of the STFI Strip Compression Tester

SUMMARY

The STFI tester is designed to measure the edgewise compression strength of medium and linerboard at a short span of 0.7mm. This study was undertaken to compare compression strength measured with the STFI tester with other commonly used compression tests and to develop a moisture compensation package which would compute the compression strength at 50% RH based on measurements made at other relative humidities.

Reasonable correlations were found to exist between STFI results and other compression strength tests. The STFI results were found to be 1.436 times higher than regular ring results, 1.416 times higher than Weyerhaeuser compression results, 1.135 times higher than FPL compression results, and 1.185 times higher than modified ring results.

The moisture compensation package was found capable of predicting the compression strength at 50% RH with an average accuracy of about ±5% and occasional discrepancies in excess of 10%.

Some difficulty has been encountered which can be related to the use of DC circuitry. It is planned to change this to AC in the near future.

DESCRIPTION OF STFI TESTER

The STFI Strip Compression Tester is shown in Fig. 1. The two pairs of clamps are independently mounted on cantilever spring steel blades. The clamps are closed pneumatically to grip the specimen at a test span of 0.7mm. The left clamp is actuated by a motor-driven cam to exert a horizontal compressive force on the free

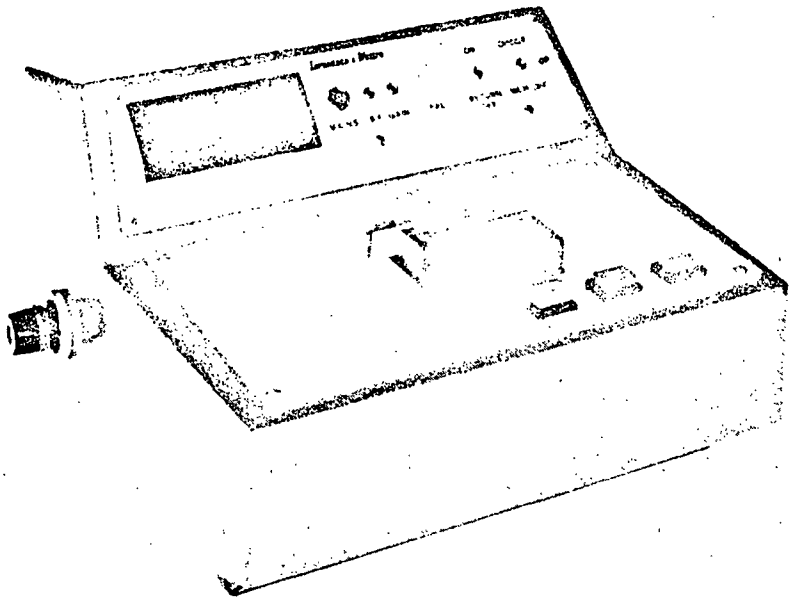

Fig. 1. STFI Strip Compression Tester

span of the specimen. The right clamp is in non-rigid contact with a load cell. The output of the load cell is indicated on a 4 decade DVM in kN/m of specimen width. The increasing force on the specimen is indicated continuously until failure of the specimen causes a reduction in force equal to 1% of the load cell capacity. At this point, the indicated force is locked in the display and the clamps automatically open and return to their starting position. A push-button start switch unlocks the display, actuates the clamps, and starts the drive motor for the next test.

The "balancing" knob adjusts the zero or the digital display to correspond to the unloaded load cell. The "return" on/off switch can be used to disconnect the return after system function in which case the drive motor will not return until the clamps move to a preset limit. The 3 position alteration switch on the far right of the tester is placed in the "OP" position for normal operation. The "check" position permits comparison of the indicated value with a predetermined number to check the state of calibration of the tester. The "memory off" position disconnects the circuit which normally locks the failure load in the display. The "SF" and "gain" potentiometers

are used for adjusting the scale and amplifying factors, respectively, when calibrating the tester with static dead weight loads.

The tester is designed to grip specimens 15mm wide by any convenient length greater than 75mm. A controller and pressure gauge permit adjustment of the clamping force on the specimen. The tester is equipped with a 200N capacity load cell, and is adequate for cross-machine direction tests on all grades of linerboard and for machine direction tests on all but the heavier weight linerboards. An optional 500N capacity load cell is available from the instrument manufacturer.

SPECIMEN CUTTER

Arrangements have been made with Testing Machines, Inc., to make available a strip cutter (a modified Concora cutter) to cut 15mm by 3 inch specimens for the STFI test.

COMPARISON OF STFI WITH OTHER EDGEWISE COMPRESSION TESTERS

Sixty-eight samples of linerboard of various weights and 15 samples of medium were obtained from various manufacturers. The samples were preconditioned at less than 35% RH and conditioned at 50% RH prior to testing. All tests are cross-machine direction.

Data for each sample were obtained with the STFI tester, with the regular ring test, with the Weyerhaeuser Lateral Support tester, with the Forest Products Laboratory Lateral Support tester, and with the modified ring test.

A summary of the results for each grade weight is given in Table I. Figs. 2-5 show the overall relationship between STFI results and the other tests, respectively

Figs. 6-11 show the within grade relationships. The correlation coefficients were calculated and the correlation lines are drawn for a 0-0 intercept.

The results in Table I and in Figs. 2-11 show that:

1. Compression strength measured with the STFI tester is significantly higher than that measured with the other tests. The within sample variance, as indicated by the coefficients of variation, is also higher. Both of these findings could, in part, result from the much shorter test span in the STFI test (see Table I).

2. The correlation between the STFI test and the other tests is quite good when determined across the entire range of grade weights (see Figs. 2-5).

3. The within grade weight correlations are not as good but are significant. The correlations are generally better for the intermediate grade weights than light and heavy grade weights. It is felt that much of the residual variation may be attributed to within sample variance (see Figs. 6-11).

It is concluded that the STFI tester is probably no better or worse than the other compression tests in its ability to differentiate between samples.

MODIFICATION OF STFI TESTER TO INSTALL MOISTURE COMPENSATION PACKAGE

Mechanical

The mechanical changes made in the STFI tester to permit installation of a moisture compensation package were those required to electrical insulate the two pairs of clamps from each other. These changes are diagrammed in Fig. 12. The two blocks, A and B, were replaced with blocks made from a non-conducting material (delrin). A non-conducting bushing (nylon), C, was constructed to insulate the cam drive from the base of the tester. Non-conducting bushings D, E, and F were also constructed to insulate the clamps from the load cell and from the two spring support posts, respectively.

TABLE I

COMPARATIVE EDGEWISE COMPRESSION DATA

	STFI Compression	Regular Ring Compression	Weyerhaeuser Compression	FPL Compression	Modified Ring Compression
26 lb Liner (13 samples)					
Average, kN/m	2.23	1.48	1.41	1.98	2.06
Average V, %	12.0	7.4	12.2	8.3	5.9
33 lb Liner (8 samples)					
Average, kN/m	2.69	1.92	1.95	2.44	2.42
Average V, %	10.9	6.5	10.2	8.3	6.1
42 lb Liner (17 samples)					
Average, kN/m	3.36	2.51	2.50	2.97	2.87
Average V, %	9.4	5.6	8.0	8.0	5.4
69 lb Liner (15 samples)					
Average, kN/m	5.66	4.11	4.12	5.09	4.70
Average V, %	10.8	4.6	7.4	7.9	4.3
90 lb Liner (15 samples)					
Average, kN/m	7.06	4.77	4.96	6.09	5.62
Average V, %	9.8	4.3	6.7	8.6	4.3
26 lb Medium (15 samples)					
Average, kN/m	3.26	2.21	2.19	2.73	3.04
Average V, %	11.2	3.9	10.0	2.9	4.8

Notes:

(1) Data are for CD compression at 50% RH.
(2) The V values are the average coefficients of variation of the individual samples.

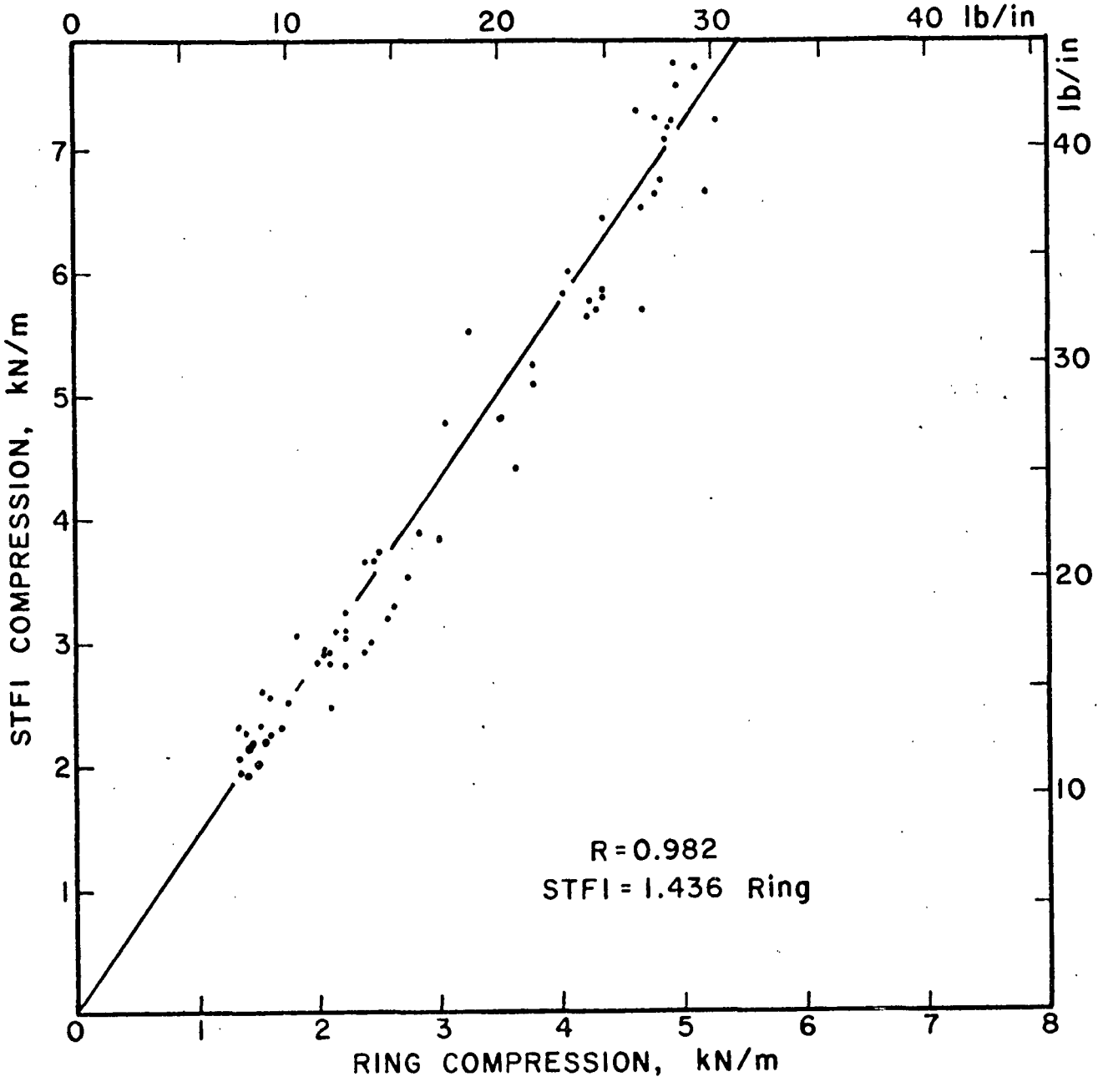

Fig. 2. Comparative Edgewise Compression Data Between STFI and Regular Ring Testers for all Grade Weights.

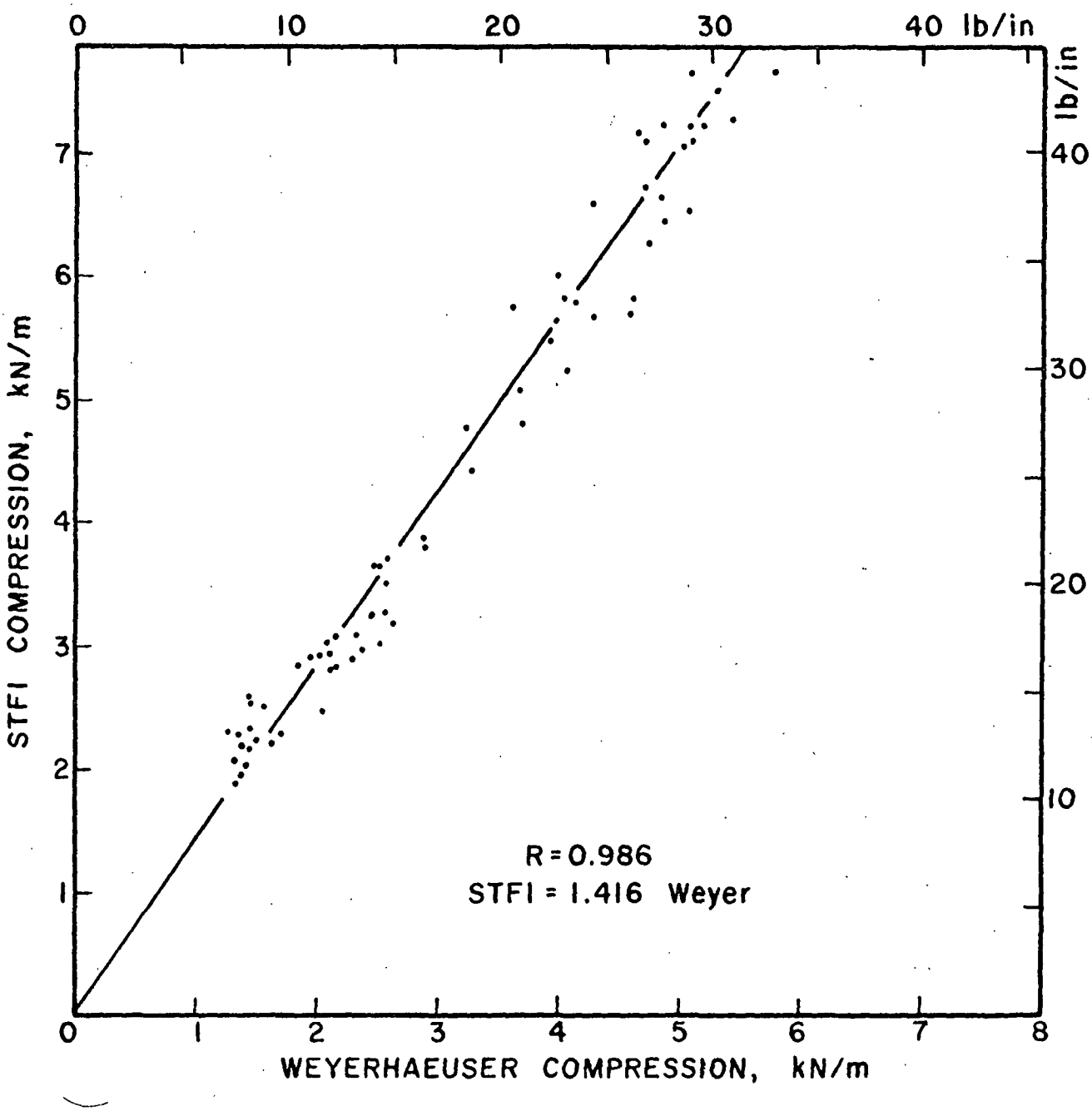

Fig. 3. Comparative Edgewise Compression Data Between STFI and Weyerhaeuser Testers for all Grade Weights.

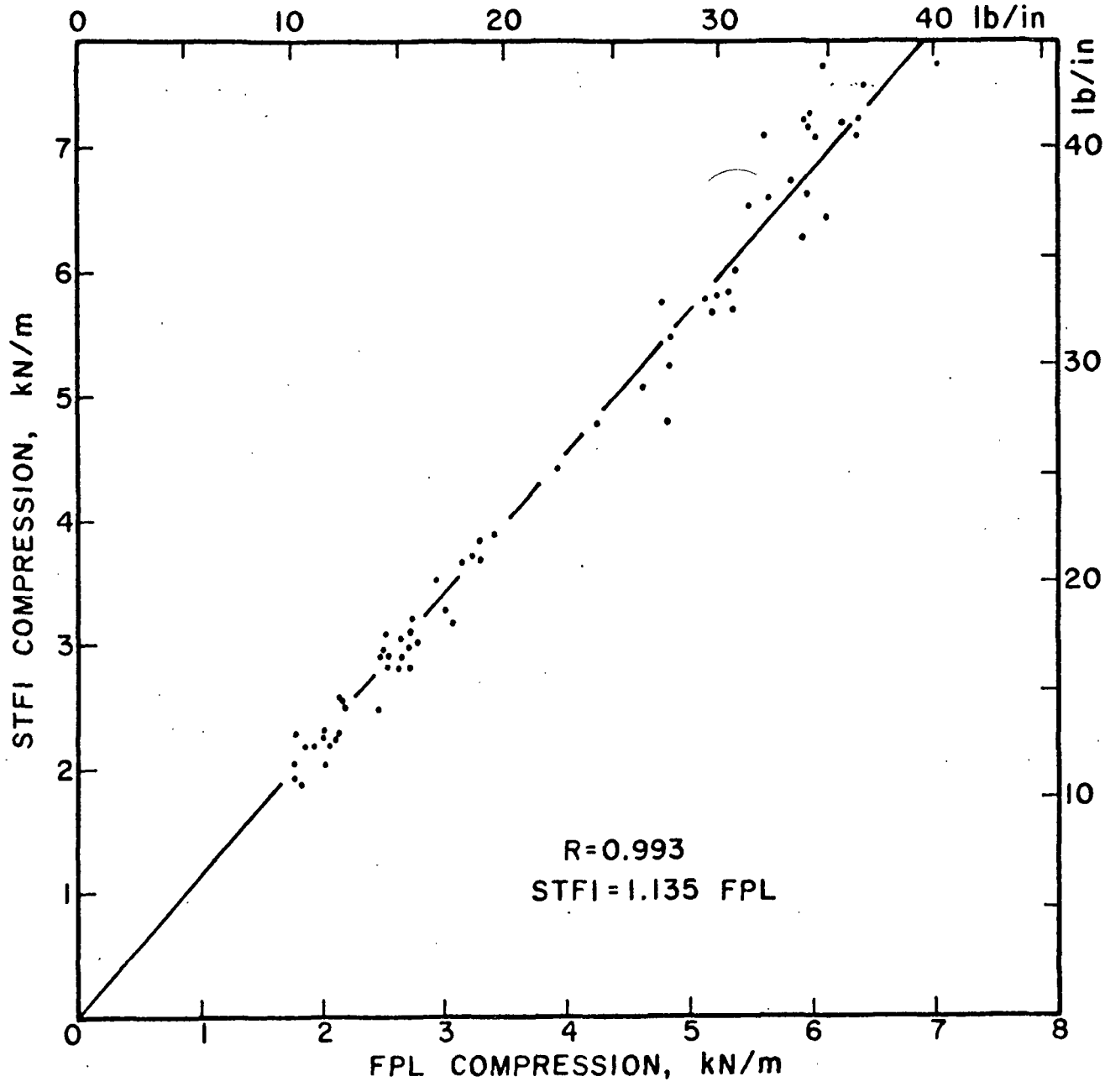

Fig. 4. Comparative Edgewise Compression Data Between STFI and FPL Testers for all Grade Weights.

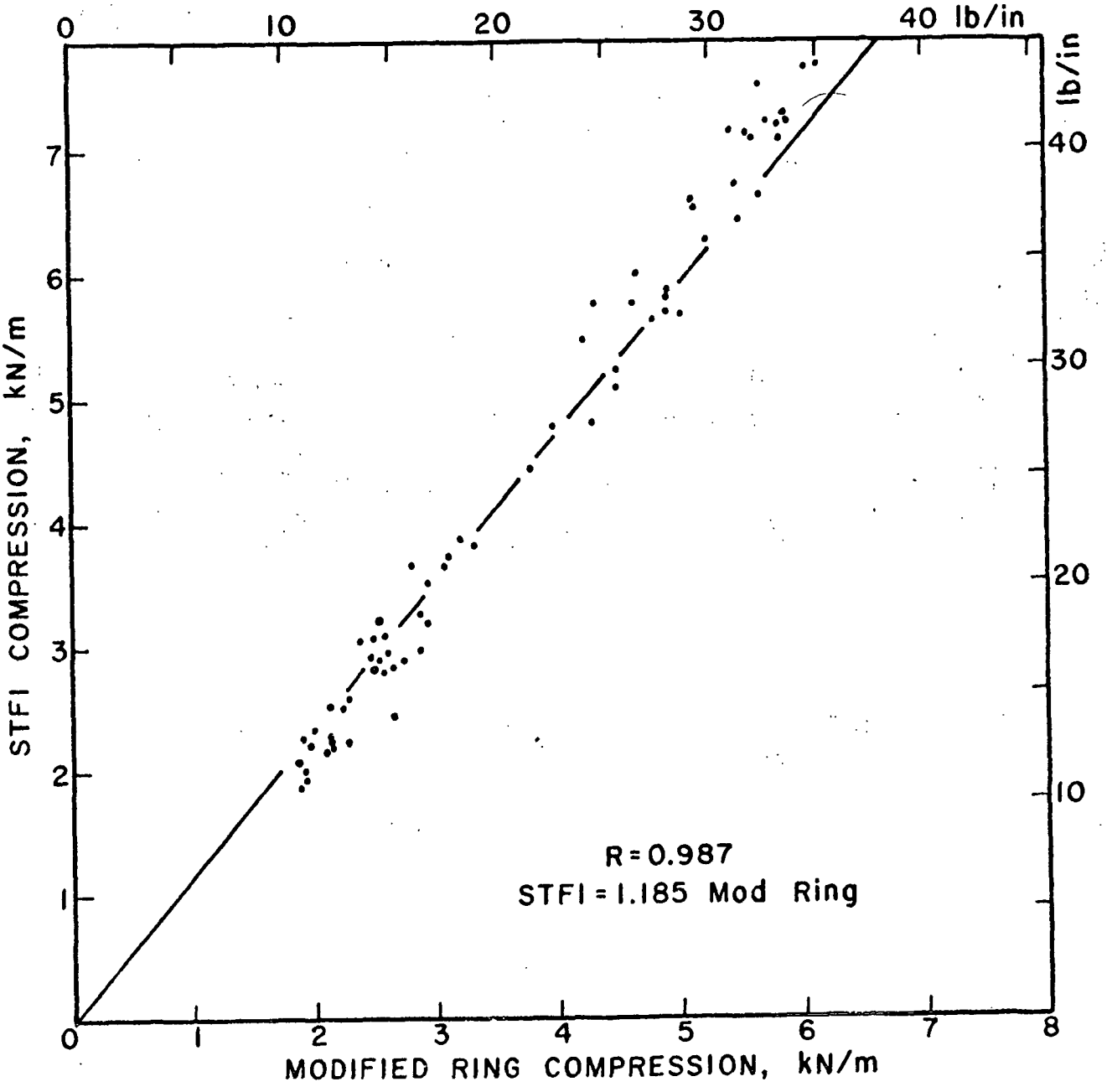

Fig. 5. Comparative Edgewise Compression Data Between STFI and Modified Ring Testers for all Grade Weights.

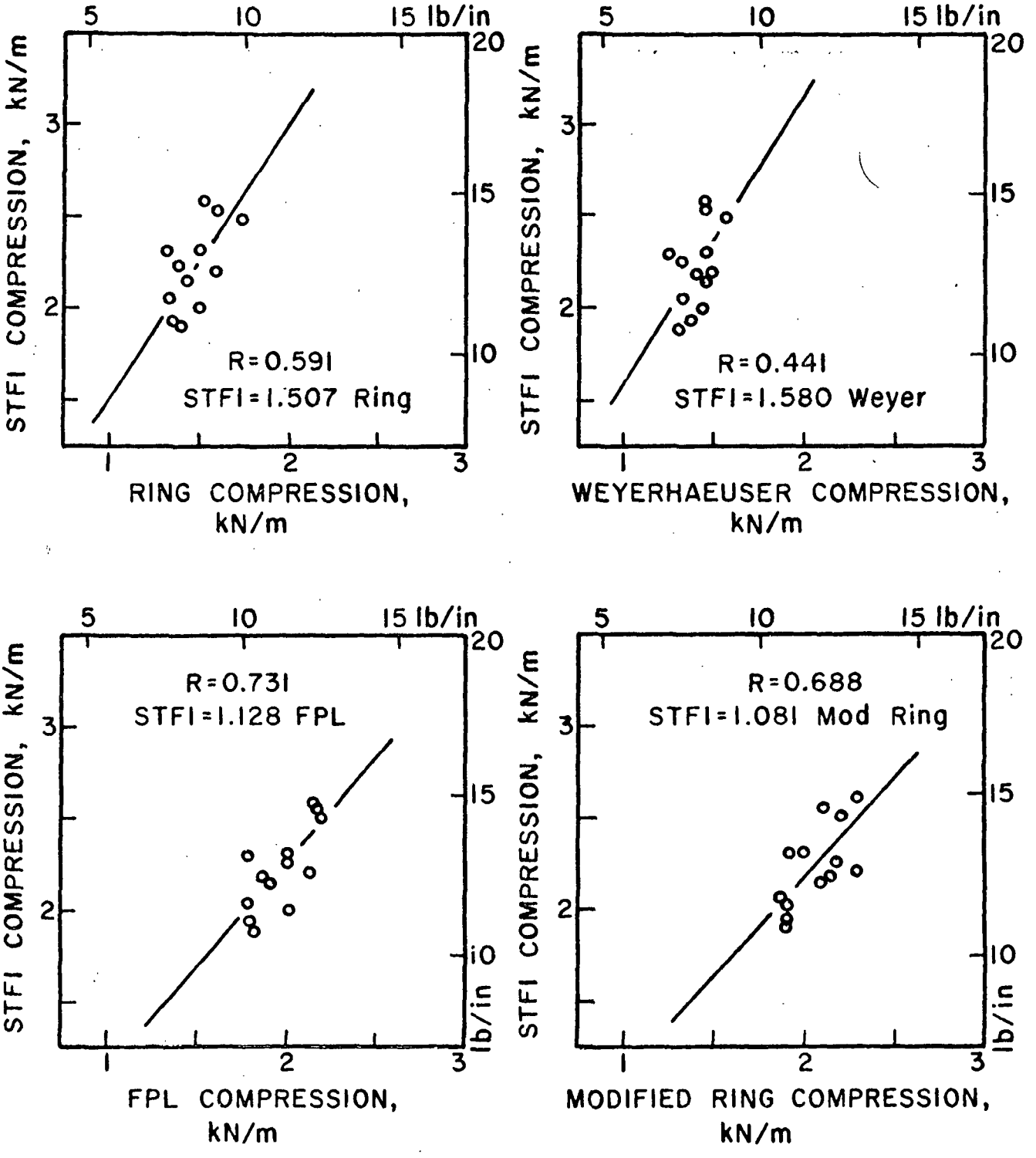

Fig. 6. Comparative Edgewise Compression Data for 26 lb Linerboard.

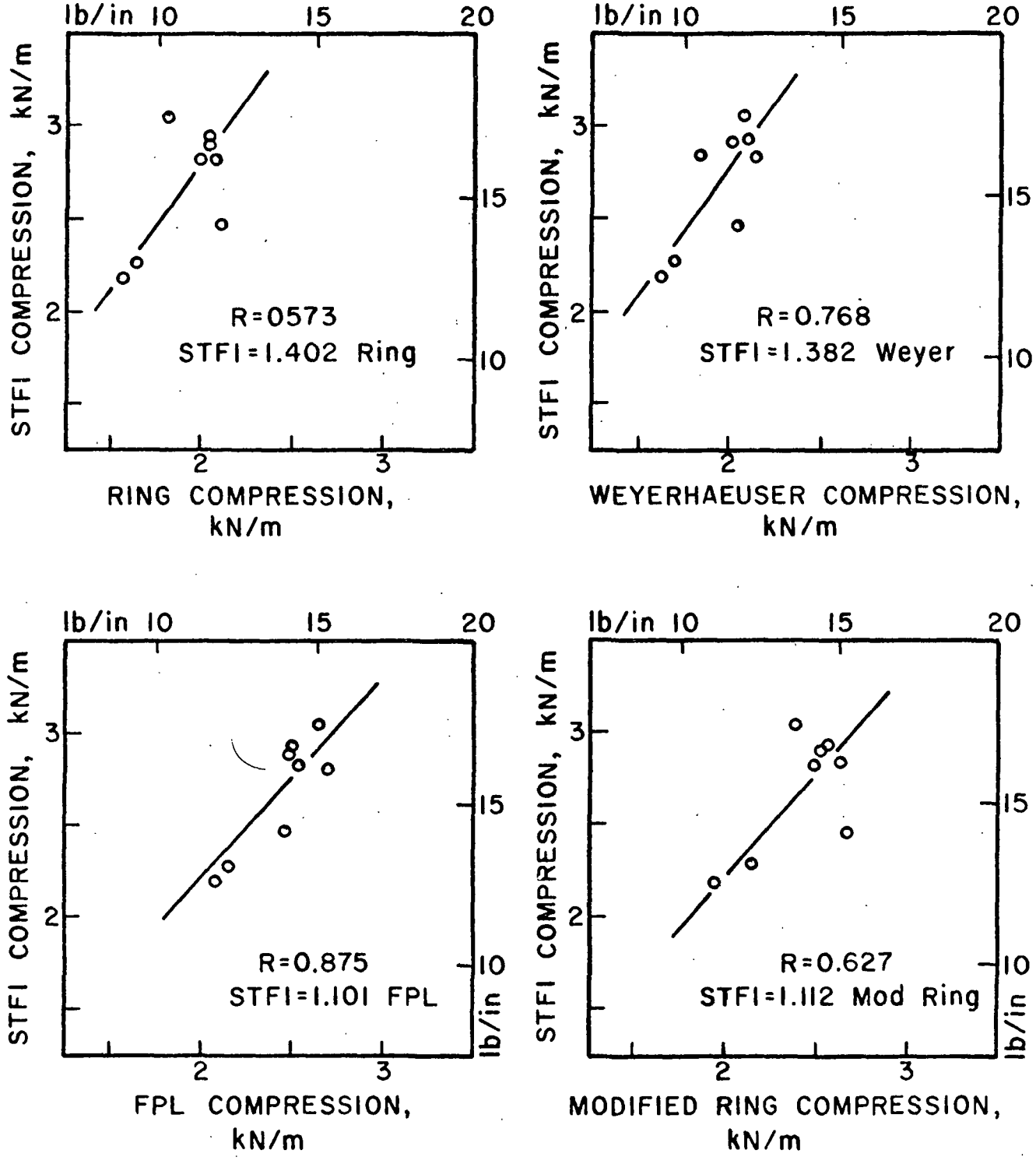

Fig. 7. Comparative Edgewise Compression Data for 33 lb Linerboard.

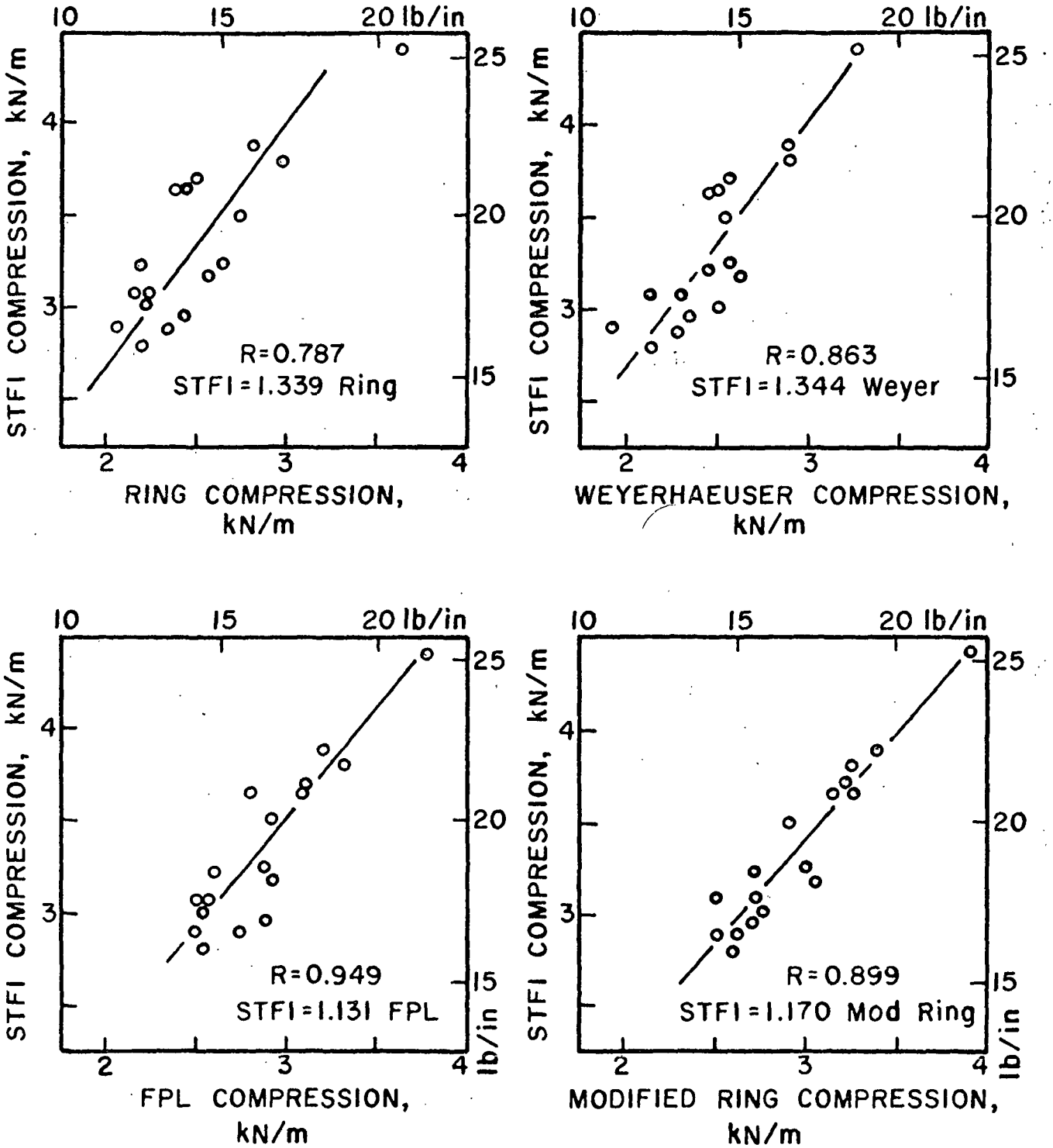

Fig. 8. Comparative Edgewise Compression Data for 42 lb Linerboard.

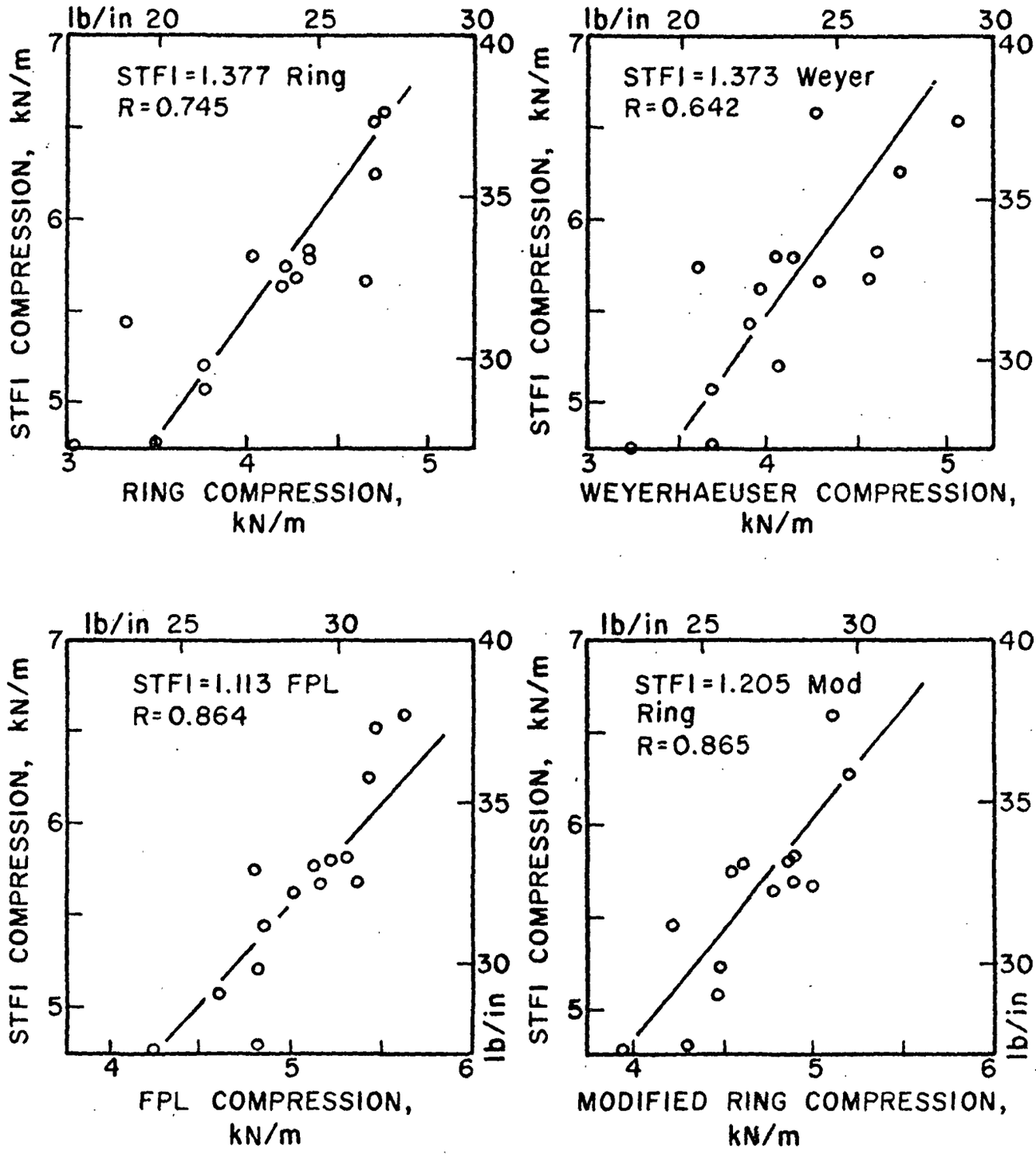

Fig. 9. Comparative Edgewise Compression Data for 69 lb Linerboard.

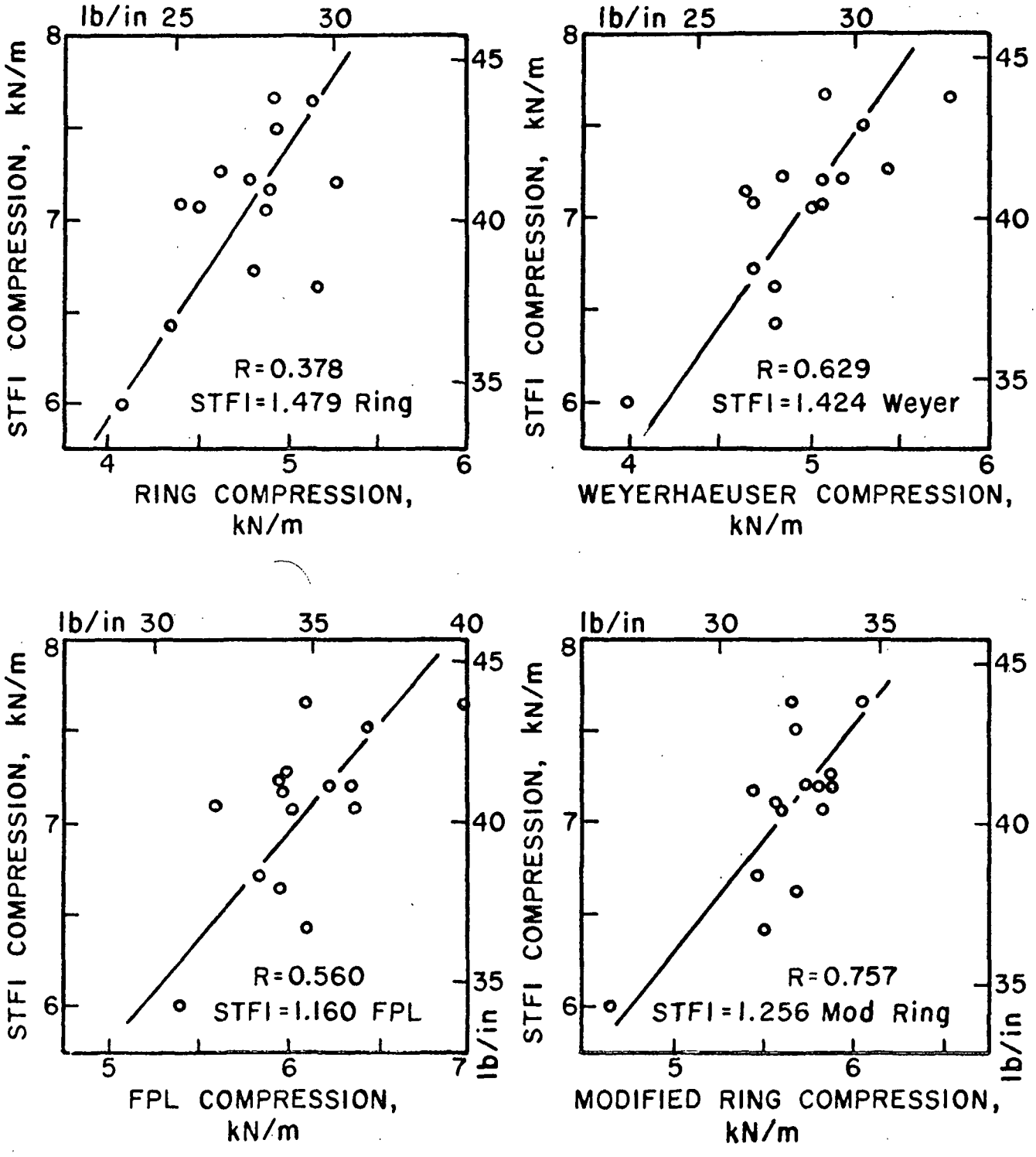

Fig. 10. Comparative Edgewise Compression Data for 90 lb Linerboard.

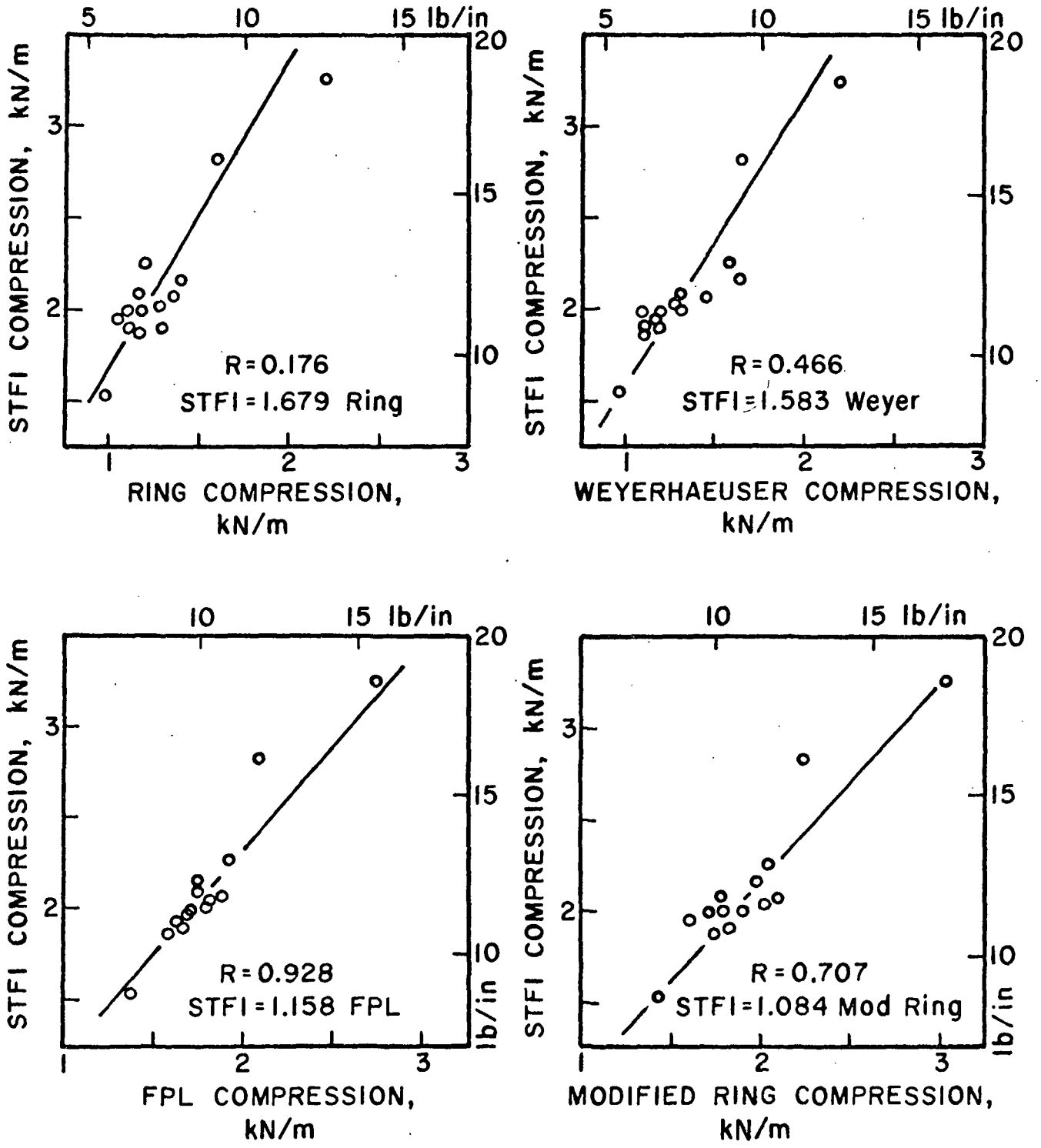

Fig. 11. Comparative Edgewise Compression Data for 26 lb Corrugating Medium.

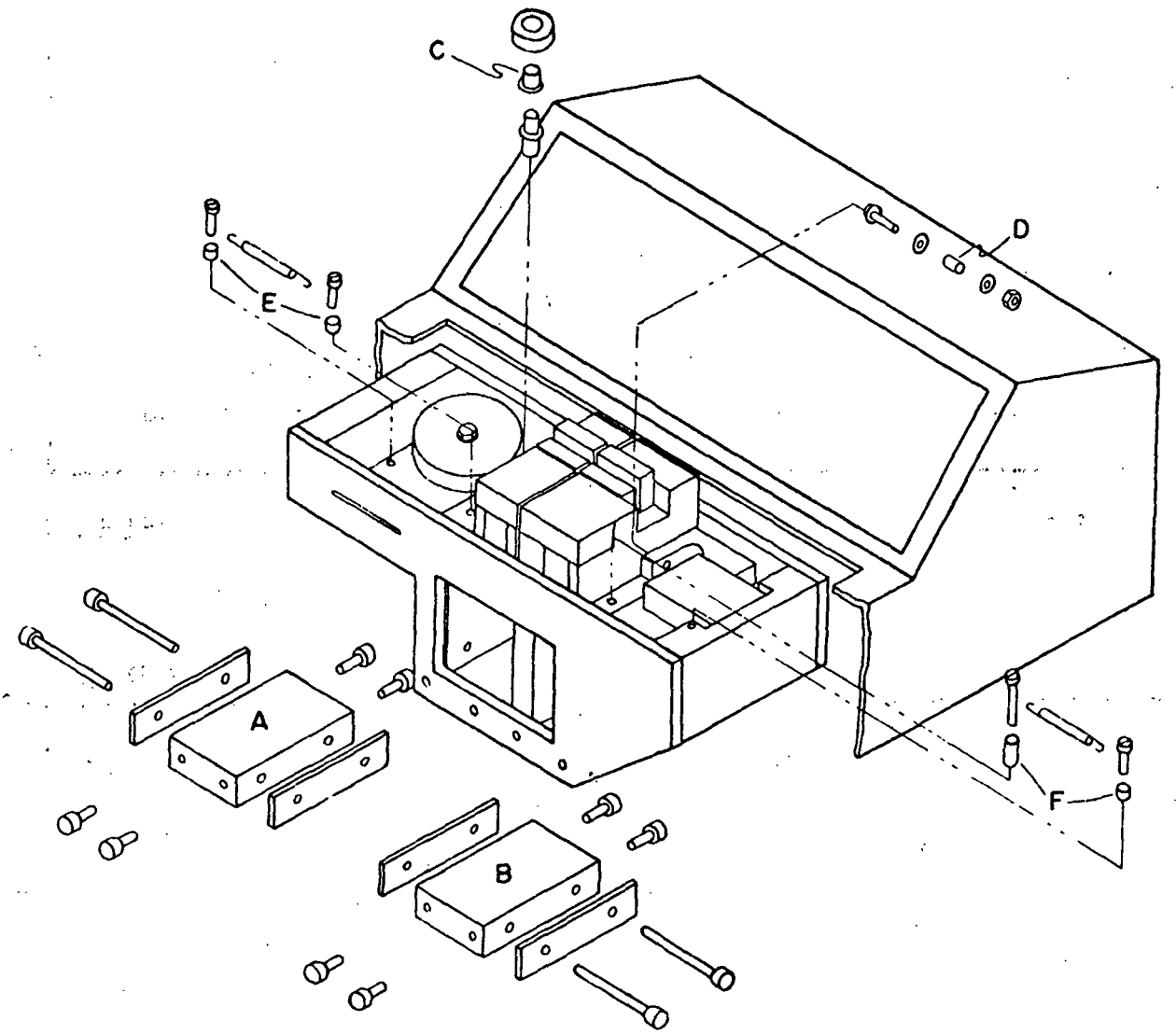

Fig. 12. Diagram Showing Modifications to STFI Tester.

Electronic

The moisture content of the sample is sensed by feeding a 10 volt DC signal into one pair of clamps and then measuring the current flow through the resistance of the sample; the latter is dependent on the actual moisture in the sample. A log amplifier is used to accommodate the large range of resistance encountered between low and high relative humidities. The output of the log amplifier is inverted so that low output values would correspond to low moisture contents.

PERFORMANCE OF MODIFIED STFI TESTER AT VARIOUS RELATIVE HUMIDITIES

The same samples used for the comparison study were used to establish baseline relationships for the modified STFI tester. Tests were made at 20, 35, 50, 65, and 80% relative humidity. Properties measured at each RH were STFI compressive strength, actual moisture content, and the inverted output of the log amplifier (f log v). An STFI ratio was calculated for each sample at each RH as the ratio of STFI compression strength at 50% RH ($STFI_R$) to STFI compression strength at the ambient RH ($STFI_A$).

Initial plots of the STFI ratio against (f log v) showed a nonlinear relationship across the entire range of relative humidities and suggested that $(f \log v)^2$ might yield a linear relationship. These plots also showed that the relationship is dependent on grade weight.

Table II presents a summary of the data showing the averages for each grade weight of STFI ratio, $(f \log v)^2$, and moisture content for each relative humidity. Analysis of the data in Table II shows that, for each grade, the relationship between STFI ratio and $(f \log v)^2$ is linear up to about 50% RH. Plots of these linear relationships are shown in Fig. 13. The regression constants for these plots are given in Table III.

TABLE II

EFFECT OF RELATIVE HUMIDITY ON STFI RATIO, MOISTURE SENSOR OUTPUT, AND MOISTURE CONTENT

Relative Humidity, %	STFI Ratio, $STFI_R/STFI_A$	Moisture Sensor Output, $(f \log v)^2$	Moisture Content, %
	Corrugating Medium (15 samples)		
20	0.822	3.8	4.8
35	0.892	14.0	6.3
50	1.000	24.0	7.7
65	1.157	38.3	8.9
80	1.658	74.6	13.5
	26 lb Linerboard (13 samples)		
20	0.849	4.6	4.8
35	0.935	15.8	6.4
50	1.000	24.5	7.8
65	1.130	40.7	9.1
80	1.588	75.2	13.7
	33 lb Linerboard (8 samples)		
20	0.847	5.3	4.7
35	0.935	16.8	6.2
50	1.000	27.2	7.7
65	1.130	42.4	9.1
80	1.588	76.7	13.6
	42 lb Linerboard (17 samples)		
20	0.848	5.7	4.8
35	0.925	18.2	6.2
50	1.000	29.9	7.6
65	1.127	45.8	9.1
80	1.615	81.1	13.3
	69 lb Linerboard (15 samples)		
20	0.853	6.0	4.7
35	0.937	18.7	6.0
50	1.000	30.5	7.2
65	1.130	47.3	8.5
80	1.625	83.4	11.9

TABLE II (Continued)

Relative Humidity, %	STFI Ratio, $STFI_R/STFI_A$	Moisture Sensor Output, $(f \log v)^2$	Moisture Content, %
	90 lb Linerboard (15 samples)		
20	0.852	6.3	4.6
35	0.938	18.4	6.1
50	1.000	31.7	7.2
65	1.127	48.3	8.4
80	1.662	83.9	11.8

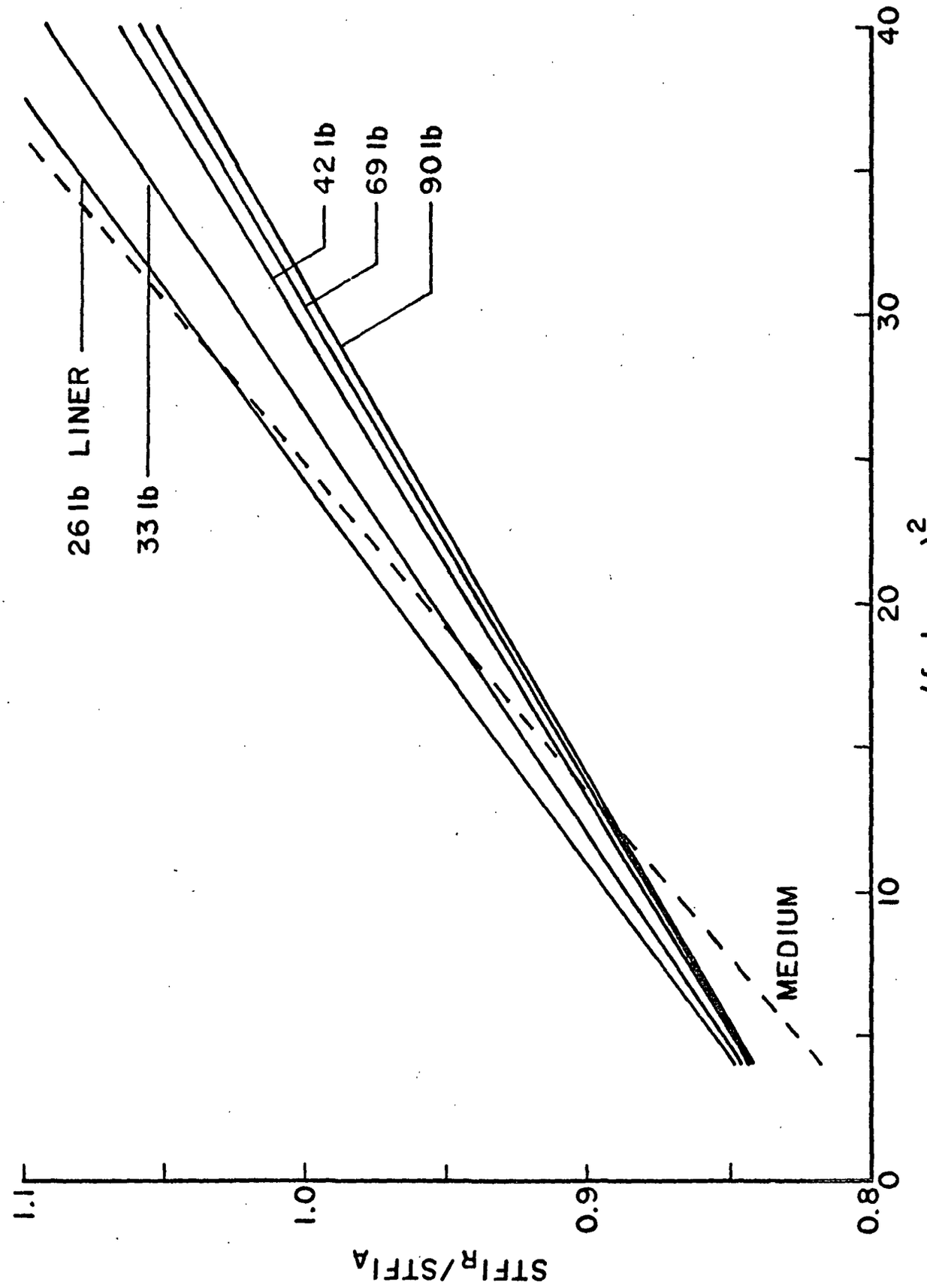

Fig. 13. The Relationship Between STFI Ratio and Moisture Sensor Output.

TABLE III

REGRESSION CONSTANTS FOR STFI RATIO VS. MOISTURE SENSOR OUTPUT

Grade Weight	Slope	Intercept	R
26 lb Medium	.00881	.782	.992
26 lb Liner	.00759	.814	1.000
33 lb Liner	.00700	.812	.998
42 lb Liner	.00628	.812	1.000
69 lb Liner	.00601	.819	.998
90 lb Liner	.00581	.821	.993

From these straight line relationships, reliable predictions of $STFI_R$ can be made from measurements of $STFI_A$ and $(f \log v)^2$ for relative humidities below 50%. Above 50% RH, use of these linear fits will give predicted values of $STFI_R$ that are too low by 2-5% at 65% RH and 13-21% at 80% RH depending on grade weight. Hence, if more accurate moisture content corrections are required, the non-linear moisture-resistance relationships must be used.

As a final check on the performance of the modified STFI tester, new samples of medium and linerboard were tested at relative humidities of 20, 35, 50, and 65%. Using the linear relationships discussed above, $STFI_R$ values were predicted and compared to actual measurements made at 50% RH. The differences between the predicted and measured STFI results are shown in Tables IV to IX. These show average prediction errors in the range of 2-5% with individual prediction errors occasionally exceeding 10%.

From the above data, it is evident that the moisture compensation curves are non-linear and that they are functions of board grade. To achieve the ultimate goal of automatic correction of data from measurements made at an arbitrary humidity level to the value expected from a measurement at 50% RH, it is necessary to implement these relationships in a modified STFI tester. We believe that this can be best accomplished

(probably cheaper, too) by the inclusion of a microprocessor in the instrument pre-programmed for all the grades. In operation, the operator would select the grade to be measured and automatically receive the uncorrected STFI value, the 50% RH value, and moisture content all on a written record if desired. A $700 laboratory microprocessor has been programmed to do this; it need only be tied to the instrument sensors to provide this capability.

FUTURE PLANS

Experience with the moisture compensation package showed that considerable "hum" was encountered during the measurement. This was eliminated by use of a capacitor which also slowed down the response time of the device. The slowed response necessitated the measurement of (f log v) at a fixed time increment after start of the test.

The above difficulty can be eliminated by the use of AC rather than DC circuitry. It is planned to make this change in the near future.

If the results presented herein are satisfactory, the next step is implementation of the concepts we have developed in a commercial package. This should be done by L & W possibly working through TMI. We are prepared to take this step at the request of FKBG.

TABLE IV

COMPARISON OF PREDICTED STFI RESULTS WITH MEASURED STFI RESULTS FOR MEDIUM

Sample	Difference Between Predicted and Measured STFI, %			
	20% RH	35% RH	50% RH	65% RH
101	-4.4	0.5	11.8	2.0
102	-1.1	-8.1	- 1.5	- 7.0
103	-0.5	-3.1	-10.5	-11.0
104	7.5	-0.8	- 1.5	- 3.8
105	-5.2	0.6	0.0	- 4.6
106	-1.6	5.8	7.9	- 5.2
107	6.8	2.3	9.1	- 0.6
108	9.6	0.0	- 0.5	2.1
109	-0.5	-0.5	- 2.4	- 6.8
110	0.0	5.1	0.0	- 5.6
Average[a]	3.7	2.7	4.5	4.9

Note:

[a]Without regard to sign.

TABLE V

COMPARISON OF PREDICTED STFI RESULTS WITH MEASURED STFI RESULTS FOR 26 LB LINERBOARD

Sample	Difference Between Predicted and Measured STFI, %			
	20% RH	35% RH	50% RH	65% RH
201	- 1.0	7.6	-1.0	3.5
202	- 2.3	- 8.0	2.8	- 6.6
203	5.4	- 0.9	1.3	4.5
204	10.9	2.2	2.7	4.9
205	6.3	9.2	2.9	- 2.4
206	1.4	- 3.7	0.9	-10.1
207	1.2	0.8	0.4	-10.8
208	4.5	-15.2	-5.4	-18.3
209	- 4.9	- 2.9	-1.0	-12.2
210	- 5.2	4.3	4.3	-11.9
Average[a]	4.3	5.5	2.3	8.5

Note:

[a]Without regard to sign.

TABLE VI

COMPARISON OF PREDICTED STFI RESULTS WITH MEASURED STFI RESULTS FOR 33 LB LINERBOARD

Sample	Difference Between Predicted and Measured STFI, %			
	20% RH	35% RH	50% RH	65% RH
301	1.9	10.1	4.3	2.4
302	-13.1	- 4.6	0.0	-12.7
303	- 4.5	- 7.6	1.7	- 9.7
304	7.6	6.9	3.1	4.1
305	- 6.8	- 5.4	-2.5	-12.2
306	- 5.6	- 2.3	1.0	- 4.6
307	8.1	- 1.1	2.5	- 9.9
308	1.8	0.4	-2.5	-10.4
309	4.0	0.7	0.7	- 1.1
310	4.2	- 7.4	-0.4	- 1.4
Average[a]	5.8	4.6	1.9	6.8

Note:

[a]Without regard to sign.

TABLE VII

COMPARISON OF PREDICED STFI RESULTS WITH MEASURED STFI RESULTS FOR 42 LB LINERBOARD

Sample	Difference Between Predicted and Measured STFI, %			
	20% RH	35% RH	50% RH	65% RH
401	4.9	8.0	-1.7	-13.6
402	3.6	- 5.6	1.0	- 9.2
403	-0.3	4.5	-1.2	- 5.2
404	9.0	13.4	1.7	5.0
405	7.6	- 4.0	-0.6	- 5.8
406	-7.0	- 6.4	-1.1	- 3.6
407	-4.6	- 5.1	-0.5	0.0
408	0.3	10.6	0.3	- 5.3
409	-1.0	- 3.0	-2.5	-15.6
410	8.4	12.5	-1.8	- 3.3
Average[a]	4.7	7.3	1.2	6.7

Note:

[a]Without regard to sign.

TABLE VIII

COMPARISON OF PREDICTED STFI RESULTS WITH MEASURED STFI RESULTS FOR 69 LB LINERBOARD

Sample	Difference Between Predicted and Measured STFI, %			
	20% RH	35% RH	50% RH	65% RH
501	-3.0	- 0.8	-1.1	- 7.6
502	4.1	12.5	1.5	- 4.9
503	8.5	- 5.0	0.0	-12.3
504	7.4	4.2	-3.0	- 9.8
505	-5.7	- 4.4	-4.8	-12.7
506	0.2	- 1.8	2.2	-10.5
507	0.0	0.7	-1.8	- 7.7
508	5.6	0.9	0.0	2.2
509	3.1	5.2	2.1	- 3.1
510	-1.5	1.5	- 1.2	- 9.5
Average[a]	3.9	3.7	1.8	8.0

Note:

[a]Without regard to sign.

TABLE IX

COMPARISON OF PREDICTED STFI RESULTS WITH MEASURED STFI RESULTS FOR 90 LB LINERBOARD

Sample	Difference Between Predicted and Measured STFI, %			
	20% RH	35% RH	50% RH	65% RH
601	1.0	2.4	3.7	- 2.6
602	2.0	3.6	-2.2	- 2.8
603	6.5	8.0	-1.6	- 1.0
604	0.1	2.1	3.0	- 8.9
605	-2.8	3.9	-0.3	- 7.6
606	-5.6	-0.1	0.3	-11.7
607	-3.0	-3.9	1.6	-11.5
608	2.8	1.8	-1.5	- 1.0
609	-4.9	-3.1	-1.6	1.9
610	-1.4	7.1	2.4	- 6.0
Average[a]	3.0	3.6	1.8	5.5

Note:

[a]Without regard to sign.